ROLE OF FERRITE ON THE CYCLIC BEHAVIOR OF A 12 Cr MARTENSITIC STAINLESS STEEL

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The cyclic behavior of a 12 Cr martensitic has been investigated at room temperature and related to its microstructure. The microstructure obtained after heat treatment (austenizing 1050°C - tempering 760°C) is identified as a mixture of ferrite and tempered martensite. The presence and the amount of the ferritic phase dominate the effect of microstructure on the cyclic mechanical properties : accommodation of the plastic deformation, fatigue strength, crack propagation...

INTRODUCTION

A number of studies (1,2,3) have been carried out on the creep and low cycle fatigue properties of 12 Cr martensitic steel. This material is of practical interest for electrical power generating, petroleum and chemical industries.

The aim of this paper is to relate the cyclic behavior with the microstructure, in particular, with the presence of ferrite embedded in the tempered martensitic lath matrix.

METALLOGRAPHIC EVIDENCE OF THE ROLE OF MICROSTRUCTURE

The as-received material used for this study is a DIN X20Cr-Mo-V 12-1 martensitic stainless steel containing 11.3 % Cr, 0.62 % Ni, 0.85 % Mo, 0.36 % V and

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0.21 % C. The heat treatment consists in austenitization at 1050°C for one hour and air cooling followed by tempering at 760°C for 2 hours and air cooling. This results in isolated islands or very thin bands (frequently along the former austenite grain boundaries) of ferrite embedded in a tempered martensite matrix. The room temperature cyclic mechanical behavior has been investigated in the 0.6 % - 3 % $\Delta\varepsilon_t$ range (4) and brings out 2 main facts :

- the cyclic stress-strain curve presents a discontinuity. Compared to the monotonic curve, a cyclic softening is observed up to $\Delta\varepsilon_t$ = 1.6 % while a cyclic hardening is noted at higher strain levels.
- the MANSON-COFFIN curve ($\Delta\varepsilon_p$ vs N_R) presents 2 slopes, on either side of $\Delta\varepsilon_p$ = 1 %.

Metallographic studies, SEM and TEM observations indicate that ferrite plays an important role in the cyclic behavior. Cycling results in formation of extrusions on the electropolished surfaces of the specimen. The extrusions are visible from the very first cycles of the test onwards. Then they grow (figure 1) and their quantity increases with strain cycling. Especially for the highest strain levels, a secondary network of smaller extrusions appears. It has been established that the main extrusions are of ferritic nature (5). Intrusions and microcracks are present near or in the vicinity of extrusions. The dislocation structures obtained in the two phases are very different. Dipolar walls and cells are indentified in ferrite while a similarly well organized substructure is not present in martensite (figure 2). Increasing strain amplitude leads to an increase of dislocation density in martensite and to cellular structure of diffuse aspect in ferrite. It is thus concluded that ferrite appears as a phase well able to accommodate plastic deformation. But at high strain level, a more important contribution of the martensite is required to accomplish the plastic deformation.

INFLUENCE OF FERRITE

In order to change ferrite amount, three different microstructures, labelled types I, II and III have been obtained by transferring specimens heated at 1050°C for 1/2 hour to an adjacent furnace preheated at 700°C and by keeping them respectively for 0, 3 or 4 hours before air cooling. Tempering (2 hours at 760°C and air cooling) was then performed on all specimens. Types I and II microstructures exhibit respectively about 8 and 17 % ferrite in the tempered martensite matrix, of similar morphology of the as-received material. However type II ferritic islands may be greater and present a rather non-uniform size distribution. Type III shows in the tempered martensite matrix a mixture (about 26 %) of ferrite and ferrite + carbides, this latter appears as rather rounded and wide areas.

Effect on Low Cycle Fatigue Strength

Room temperature LCF tests are carried out at two strain levels : $\Delta\varepsilon_t$ = 1 % and 2.5 %. The number of cycles to failure for all conditions is represented as histograms in figure 3. It is observed that type II displays the best fatigue performance and type III the worst one at $\Delta\varepsilon_t$ = 1 %. The fatigue lives obtained at $\Delta\varepsilon_t$ = 2.5 % are similar for types II and III while they are shorter for type I. It can be noticed that the ratio of elastic strain range on total strain range for the stabilized loop is greater for type I than for types II and III (about 5 % at $\Delta\varepsilon_t$ = 1 % and 3 % at $\Delta\varepsilon_t$ = 2.5 %). Then, the fatigue strength is significantly influenced by the amount of ferrite and also by its morphology : the presence of a greater amount of carbide free ferrite leads to a better fatigue resistance.

Effect on Fatigue Crack Propagation

U-notched CHARPY specimens with lateral etched sides are used to study the effect of ferrite on fatigue crack propagation. Three points bending fatigue tests are performed under a mean stress σ_m = 110 MPa, a ratio R_σ = 0.3 and a sinusoïdal wave of 5 Hz. The tests are periodically interrupted to allow optical microscope observations and the applied number of cycles is related to the measured crack length. This procedure is suitable for such metallographic and qualitative investigation but not for the measurement of crack growth rates.

Figure 4 displays the evolution of the crack length a with the number of cycles $N-N_i$, where N_i is the number of cycles to initiate a 200 μm crack length. This clearly shows that crack propagation is delayed (type II>type I>type III) with the presence of greater quantity of ferrite without carbides.

Photomicrograph (figure 5) indicates that crack path is influenced by the presence of ferrite and depends on its orientation with the crack. When the ferritic island is perpendicular to the crack path, the crack tends to branch during its crossing. If ferrite is inclined with the crack path, the crack tends to pass round it. Both cases require an excess of energy to propagate the crack and this leads at least locally to a decrease in crack growth rate. Though the crack growth rate curve is not here obtainable, rough calculation indicates that ΔK reaches about 5 $MPa\sqrt{m}$ at the end of the test. So crack propagation mainly occurs in the first stage of the $da/dN-\Delta K$ curve and the effect of microstructure is pronounced at this stage. Since type II material contains the greatest amount of carbides free ferrite, the crack in this steel will meet more soft obstacles able to harden resulting in crack branching and more obstacles to pass round. This leads to a retardation of the crack at least in the region of low ΔK. For higher ΔK, though it has not been here observed, this effect should be probably reduced (6).

REFERENCES

(1) Eggeler, G., Nilsvang, N. and Ilschner, B., St. Research, 2/87, 1987, p.97.

(2) Gooch, D.J., Metal Science, 16, 1982, p.79.

(3) Kanazawa, K., Yamaguchi, K. and Kobayashi, K., Mat. Sc. Eng., 40, 1979, p.89.

(4) Degallaix, G., Vogt, J.-B. and Foct, J., Proc. 2nd LCF and elasto-plastic behavior of materials, Münich, FRG, 1987, p.95.

(5) Vogt, J.-B., Degallaix, G., Tissier, J.-C. and Foct, J., to be published in Jl Mat. Sc. L., 1988.

(6) Yokobori, T., Kawada, I. and Mata, H., Rep. Res. Inst. Strength and Fracture of Materials, 9, 1973, p. 35.

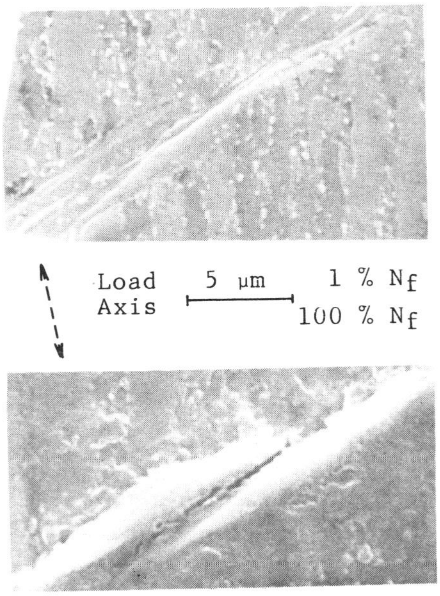

Figure 1 : ferrite extrusion. specimen tested at $\Delta\varepsilon_t$=2.5%

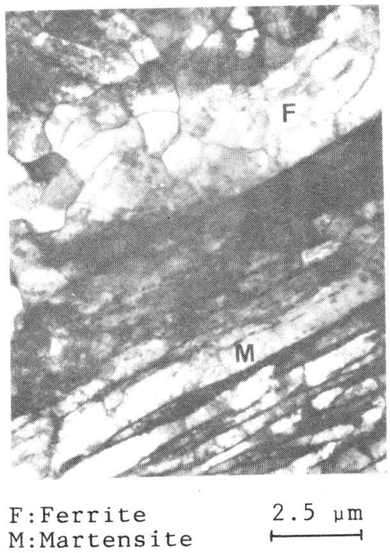

Figure 2 : TEM=structure developed at $\Delta\varepsilon_t$=1%

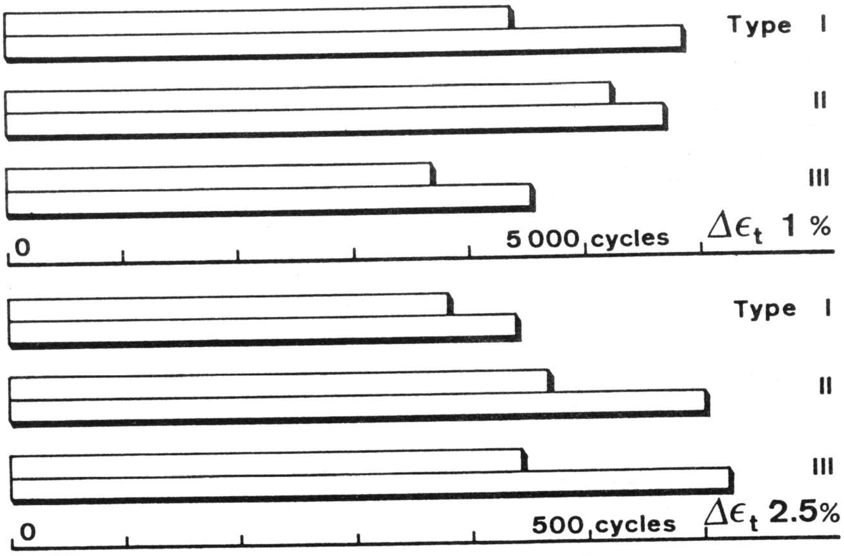

Figure 3 : fatigue lives at $\Delta\varepsilon_t$=1% and 2.5%

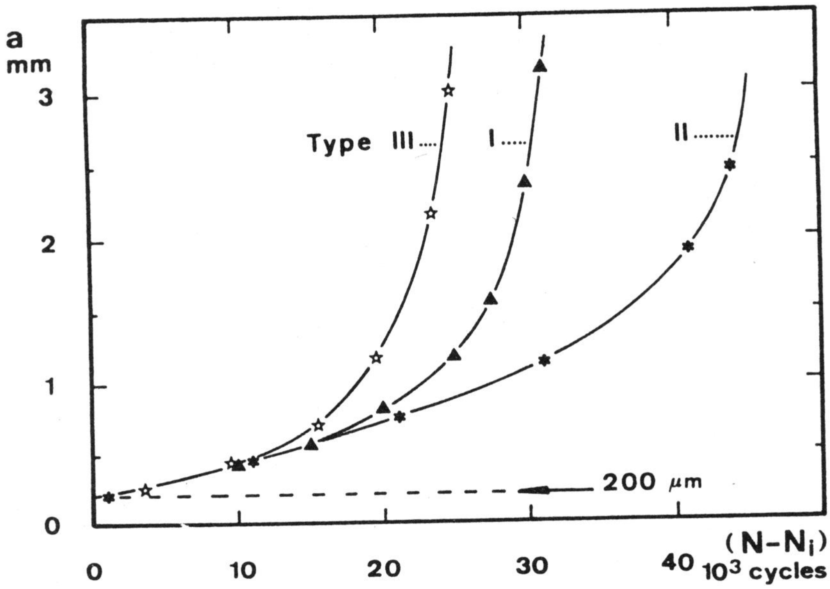

Figure 4 : Evolution of crack length with cycling

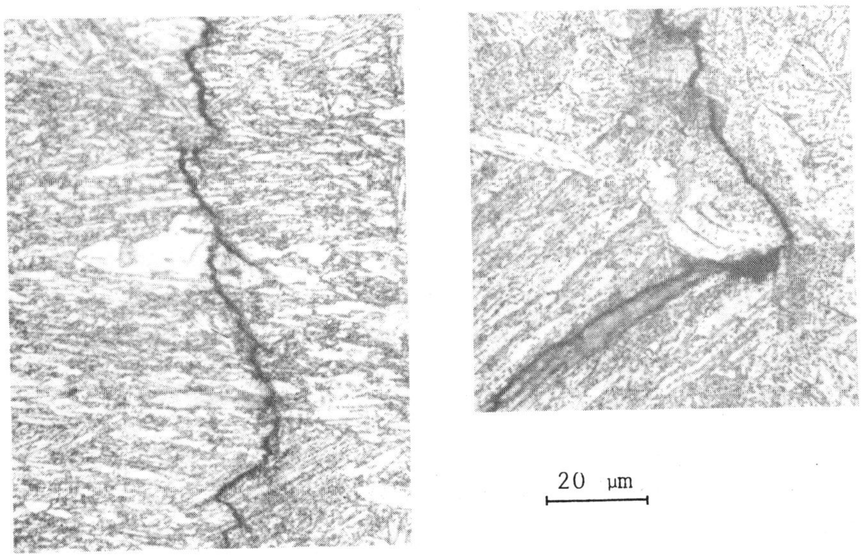

Figure 5 : a) crack branching in ferrite (type II)

b) crack rounding ferrite+ carbide obstacle (type III)